North Dakota Geological Survey
100K Series: Blfd - g - Dd

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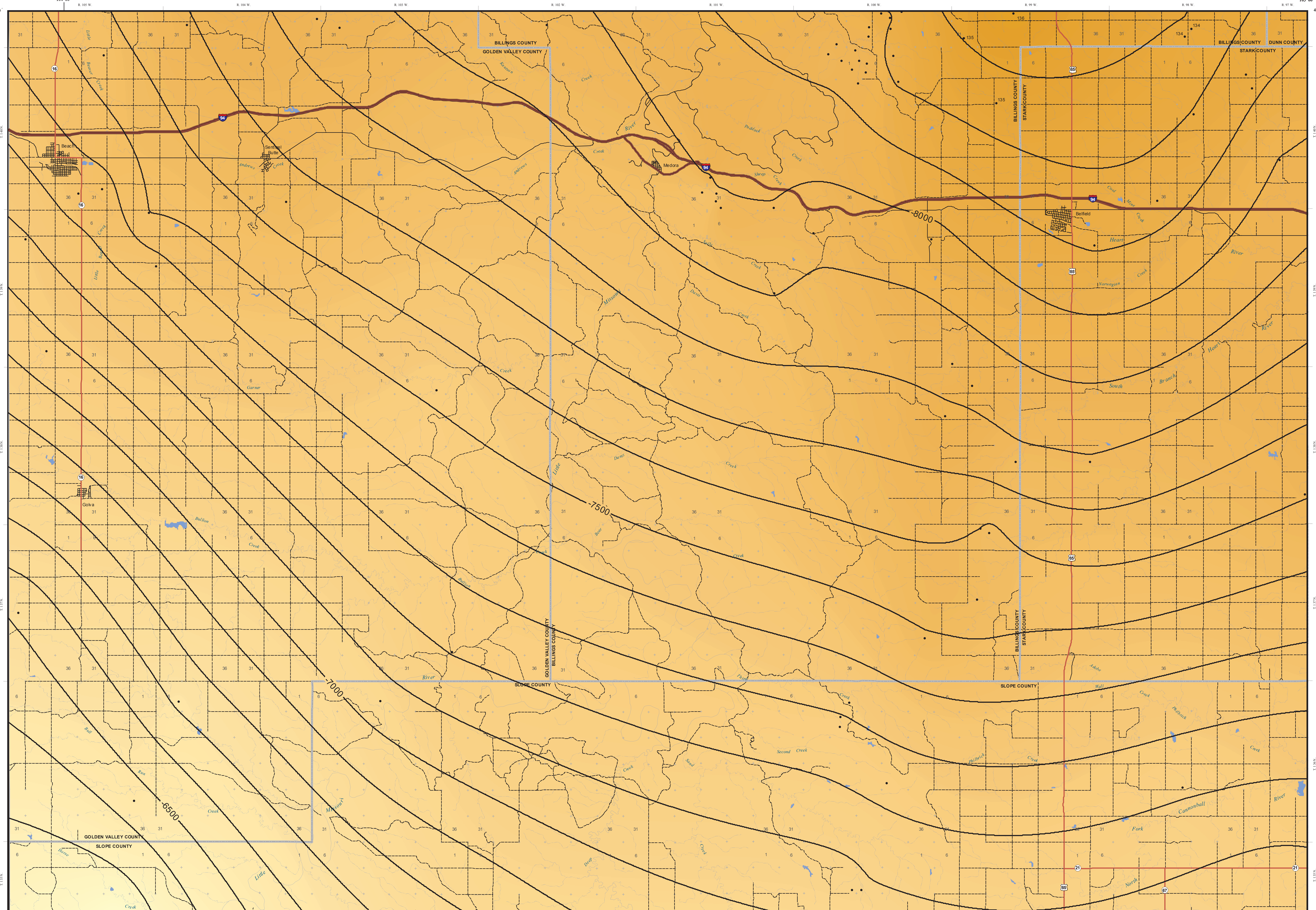
Deep Geothermal Resources: Estimated Temperatures on Top of the Duperow Formation

Belfield 100K Sheet, North Dakota



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2012

Geothermal energy is a renewable resource capable of producing an uninterrupted supply of electrical power and heat. In stable sedimentary basins, low-temperature geothermal energy (<40°C) is extracted from the shallow subsurface (~2-200 m [8-600 feet]) for use in domestic and commercial heating and cooling systems. Historically, deeper, hotter resources in these regions have not been developed because they typically lack one or more of the essential requirements that make high-temperature geothermal resources technically and economically viable.

Conventional methods of electricity generation using geothermal energy rely on hot (> 100°C) relatively shallow (<3,000 m [10,000 feet]), easily developed hydrothermal resources. Generally associated with active plate boundaries and/or volcanism, these high-grade hydrothermal systems are characterized by high thermal gradients, and highly fractured, porous reservoir rocks through which natural waters or steam can freely circulate. Large-scale, cost-effective electric power generation usually requires fluid temperatures above 150°C but smaller systems based on standard binary-cycle technology are capable of producing electricity using geothermal fluids at temperatures as low as 100°C.

Natural sources of high-grade hydrothermal energy are geographically limited. In the U.S. they are restricted to the western states and currently represent less than 1% of the nation's electrical power generating capacity (U.S. Energy Information Administration, 2011). Yet the amount of heat at depths less than 10,000 m (30,000 feet) below the surface of the continental U.S. is substantial. By replicating natural hydrothermal conditions it is possible, in some regions, to turn this heat into an economically viable resource. In 2005 an 18-member MIT-led interdisciplinary panel conducted a comprehensive technical and economic assessment of geothermal energy as a viable source of energy for the U.S. (Tester and others, 2006). The study estimated that, based on current technology, geothermal energy could be producing more than 100GW of affordable electricity by 2050, equivalent to roughly 10% of the U.S.' present-day capacity.

Enhanced (or engineered) geothermal systems (EGS) are engineered reservoirs designed to produce energy as heat or electricity from geothermal resources that are otherwise not economical due to lack of water and/or permeability (U.S. Department of Energy, 2008). EGS technology uses adaptations of techniques developed in the oil and gas, and mining industries to fracture hot, low-porosity rocks in the deep subsurface and extract the heat with water via a system of injection and production wells.

With infrastructures already in place and the abundance of horizontally drilled and/or artificially stimulated wells, hydrocarbon fields are prime candidates for the application of EGS technology. Of particular interest are those wells regarded as marginal or unproductive because they produce too much water. Geothermal waters that are coproduced with oil and gas are an expensive waste product that in North Dakota must be disposed of by re-injection into the subsurface. If sufficiently hot (>100°-150°C) and available in sufficient quantity, however, these waters may be capable of generating cost-effective electricity (McKenna and others, 2005).

The Devonian-age Duperow Formation is the second-deepest of four major geothermal aquifers that occur in the Williston Basin. The map shows calculated temperatures (°C) for the top of the Duperow Formation in the vicinity of Belfield in southwestern North Dakota.

There are no data sets for North Dakota that list accurate temperatures for Paleozoic rocks. Bottom hole temperatures from oil well logs are unreliable and to assume that a simple linear relationship exists between temperature and depth would be incorrect. Although grossly linear the geothermal gradient in the upper lithosphere is significantly affected by thermal variables (heat flow and thermal conductivity) in the earth's crust and any method used to accurately calculate subsurface temperatures must take these factors into account. Provided the subsurface stratigraphy is known, Gosnold (1984) showed that at a given depth (Z) the temperature (T) can be represented by the following equation:

$$T = T_o + \sum_{i=1}^{n} Z_i(Q/K_i)$$

Where:
T_o = Surface temperature (in °C)
Z_i = Thickness of the overlying rock layer (in meters)
K_i = Thermal conductivity of the overlying rock layer
N = Number of overlying rock layers
Q = Regional heat flow

For the data set used to produce this map T_o and K were assumed to be constants. Mean surface temperature T_o = 8.0°C [46.4°F] was calculated from statewide average annual bare and turf soil temperatures at 79 North Dakota Agricultural Nework climate monitoring stations for the period 1991 to 2010 (http//www1.ndsu.edu/ndsco). Thermal conductivities (K) for formations overlying the Duperow Formation are shown in Table 1.

Estimated regional steady state heat flow Q = 70.0 mW/m^2 (Blackwell and Richards, 2004).

Rock units and thicknesses were obtained from oil well log tops (March 2012 update). The map was compiled using approximately 75 data points (wells).

Table 1. Thermal conductivity estimates for principal lithostratigraphic units overlying the Duperow Formation in the Williston Basin.

Formation(s)	Thermal Conductivity (W/m K)[1]	Formation(s)	Thermal Conductivity (W/m K)[1]
Quaternary, Neogene and Paleogene systems, Hell Creek, Fox Hills	1.75	Big Snowy Group	1.30
Pierre, Niobrara, Carlile	1.46	Kibbey (limestone marker bed)[2]	1.40
Greenhorn	1.25	Madison Group	3.10
Mowry, Newcastle	1.72	Bakken	1.20
Inyan Kara	[illegible]	Three Forks	1.40
Swift	1.41	Birdbear	3.50
Rierdon	2.13		
Spearfish	2.59		
Broom Creek, Amsden	5.20		
Tyler	1.40		

[1] Thermal conductivities for formations above, and including, the Spearfish were estimated using data from temperature-depth logs for Hess Corporation's Tioga-Madison Unit O-143HR well in SW4, NW4, Sec. 17, T158N, R94W. All other thermal conductivities are from Gosnold (2009).
[2] The Kibbey Lime is a limestone bed in the Kibbey Formation that is a prominent marker on electronic logs.

References

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Geologic Symbols

Top of Duperow Formation (feet above sea level)

Data Points. Selected points show temperature in °C

Temperature/°C

136 134 132 | 132 130 128 | 128 126 124 | 124 122 120 | 120 118 116 | 116 114

Other Features

Water
Waterway - Perennial
Waterway - Intermittent
Section Corners
County Boundary
Interstate Highway
US Highway
State Highway
Paved Road
Unpaved Road

Scale 1:100,000

0 1 2 3 4 Miles

Mercator Projection
Standard parallel 46°30'
1927 North American Datum
Central meridian 103°30'

Belfield 100K Sheet, North Dakota

Glendive	Grassy Butte	Killdeer
Wibaux		Dickinson
Baker	Bowman	Mott

Adjoining 100K Maps